

A general account of the Geology of the Malay Peninsula and the surrounding countries, including Burma, the Shan States, Yunnan, Indo-China, Siam, Sumatra, Java, Borneo and other Islands of the Dutch East Indies.

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Introduction.

This account is a digest of the writings of many geologists. It would occupy too much space for me to detail all of them, but most of my information was derived from the following:— La Touche on the Northern Shan States, Middlemiss on the Southern Shan States and Karenni, Coggin Brown on Burma and Yunnan, Résultats de la mission géologique et minière du Yunnan méridional, Sept. 1903—Jan. 1904, Situation de l'Indo-Chine de 1902-1907, Scrivenor on the Malay Peninsula, Molengraaf on Borneo, Van Cappelle on the West Coast of Sumatra, Wing Easton on West Borneo, Verbeek on the Moluccas, Amboyna, Banka, and Billiton, and various authors in the *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië*.

The area dealt with includes Burma, the Shan States, Yunnan, Siam, Indo-China, the Malay Peninsula, Sumatra, Java, Borneo, and the intermediate islands. Unfortunately, the most satisfactory method of presenting a general idea of the geology, namely to prepare a geological map and to base the discussion on it, is not available, because the geological structure of most of the countries has not been mapped. In spite of this, enough is known, even in the least known regions, such as Yunnan, and parts of Indo-China, to compare the rock formations of any particular period in the different countries, and from the present features it is possible to trace the effects of certain wide-spread earth-movements which have affected all the countries in the area, and to compare them with the effects on neighbouring lands.

Large gaps occur in our knowledge of the area, so blanks must exist in our comparison of the structure of the different countries. It must be admitted, however, that these gaps are not always the result of imperfect knowledge of the countries in question, for, in more than one case, geologists are at a loss to account for phenomena in countries where the structure is

known in considerable detail. For example, no explanation has yet been given of the recently extinct volcanoes which occur in a belt of Tertiary beds in Burma, between the Irrawaddy and the Shan States. If they were situated near the great fault-plane which passes from north to south many miles to the east, their presence could easily be explained, but their occurrence in Tertiary beds, so far from this great fault, is a mystery.

Earth Movements.

The geographical and geological features of the area were established as the result of folding-movements of at least three different periods, but the earth-movement in the late Mesozoic period (Hercynian), and the Tertiary earth-movement, which affected Europe, North Africa, and the other parts of Asia, have had a more widespread effect on our area than the earliest one. Folding movements before the Mesozoic period took place on a large scale only in the northern part of the area, Indo China and probably Yunnan, although the presence of fragments of granite in volcanic ashes and tuffs in Singapore, probably older than the Mesozoic granite of the Malay Peninsula, and the Palaeozoic granite, older than Permian, alluded to by Verbeek in describing the geology of Amboyna, are indications that this earth-movement took place to some extent also in the Malay Peninsula and East Indies.

The influence of the later movements is very marked in all of the countries under consideration, and successive parallel mountain folds, arranged roughly *en échelon*, can be traced through the area, beginning in the northwest, near Tibet, at the eastern end of the huge Himalayan mountain range. To these folds Suess gave the name "Coulisses," and, talking of our area, he says, "Then, in the Shan States of Burma, several of the coulisses which approach from the north and northeast disappear beneath a karst-like plateau of Palaeozoic limestone, which is folded and owes its tabular form to denudation. Fresh coulisses make their appearance in the south and form the Malay Peninsula. . . . "In this way the mighty swell of the Altai in Thibet subsides and is dispersed. The whole continent becomes lower. Many coulisses disappear. Only a few long branches are continued 'on the east into the cordillera of Annam; on the west, always giving rise to fresh coulisses, through the Malay Peninsula, and still further, to Java and beyond."

The most prominent coulisse in the western part of the area is the Naga-Arakan-Andaman-Nicobar-Barissan fold, with its axis extending from Upper Burma in the northwest, running south through the Andaman Islands, and the Nicobar Islands, and turning east through Sumatra and Java. Another important coulisse can be traced as the Main Range in the Malay Peninsula, through Singkep and Banka, and the result of the earth-movement which caused this particular fold was the intrusion of the Mesozoic granite, accompanied by the mineralisation from which originated the

world's richest tin deposits. A coulisse between these two begins in Siam, and runs in a direction slightly west of south into Upper Perak whence it extends as a granite mountain range passing near Taiping to the Dindings, and, according to a Dutch geologist, along the east coast of Sumatra, masked by more recent beds, passing through Billiton in an easterly direction, and turning northeast through the centre of Borneo, and up through the Philippines out of our area. Another important fold or coulisse is represented by the Annam cordillera, perhaps continued south into either the Anamba Islands or the Natuna Islands, and thence into Borneo.

The Mesozoic folding was more intense, in the greater part of the area, than that which affected the Tertiary rocks, and this is shown by the fact that the Tertiary rocks often have gentle undulating folds, whereas the Palaeozoic rocks, upon which they unconformably rest, are vertical or highly inclined. However, the Tertiary beds were subjected to intense earth-movements in some districts, as, for example, in Eastern Yunnan, and after folds had been denuded away, great faults cut across the region, at about the end of the Pliocene, probably giving rise to the lakes in which the late Tertiary fresh-water beds were laid down.

In Western Yunnan there were strong folding movements after the Permo-Carboniferous and before the upper Permian period.

Stratigraphical Sequence.

The mountain folds which were described above have been eroded, with the result that there are now exposed strata of all ages, since the period before the dawn of life on the earth. All the countries of our area, south of Burma, formed part of the Palaeozoic continent of Gondwanaland, which remained as a permanent land surface from pre-Cambrian times until Devonian or Carboniferous, and no fossiliferous rocks of pre-Carboniferous age are known, except in the north. Earth-movements and aerial denudation of the later rocks, in Yunnan and the Shan States of Burma, have brought these old rocks to the surface.

Pre-Cambrian.

Many Dutch geologists have expressed the opinion that the "oudeschiefer" (old schist or old slate) formation of the East Indies is, in part, pre-Cambrian, though they admit that where it is not overlain by Carboniferous limestone it may be of Mesozoic age. Some of these geologists have correlated the "oudeschiefer" with the schist series of the Malay Peninsula, the greater part, and perhaps the whole, of which is of Rhaetic age and later, so it appears that there are good grounds for not yet accepting any part of the "oudeschiefer" as pre-Cambrian. In this account we will postpone a description of this "old schist" formation until we are describing the younger Palaeozoic and the Mesozoic formations.

In Yunnan the succession of pre-Cambrian rocks is as shewn below.

* * * * Unconformity * * * *

2. Kao Liang system. Phyllites, quartzites, slates, and an occasional calcareous horizon. In part pre-Cambrian and part Cambrian.

* * * * Unconformity * * * *

1. A basal mass of gneisses and schists underlying all recognised groups.

The basal gneisses and schists are so metamorphosed that it is impossible to determine their original character, except that a small proportion are recognised as metamorphosed sediments. They are intruded by granites which are relatively young, though some of them may be pre-Cambrian.

In the Northern Shan States there is a large development of Archaean gneisses resembling those of South Western Yunnan in that they possess a similar N.E.—S.W. strike. The general mass are of intermediate chemical composition, and they consist of biotite gneisses, which are often remarkably rich in garnets, and which are interfoliated with more acid rocks, including pegmatites and graphic granites. The orthoclase of these last rocks is not infrequently converted into moonstone; often it is more completely altered into epidote, muscovite, and kaolin. In Nyounggouk district these acid rocks contain pink and blue tourmaline (rubellite and indicolite), and it is probably from rocks of this class that the fine gem rubellites are derived.

With the gneisses there occur certain subordinate rocks of basic and sometimes ultra-basic composition, including pyroxene gneisses and pyroxene granulites, and with these rocks, and particularly with the ultra-basic types, certain remarkable crystalline limestones, containing rubies and spinels, are most intimately associated.

A series of mica schists occurs to the south of the ruby mines area, and they seem to pass upwards into the Chaung Magyi series, so being either pre-Cambrian or Cambrian.

The Kao Liang system in Yunnan is certainly in part pre-Cambrian, and partly Cambrian. It occurs as bands, running from north to south, which widen somewhat as they are traced to the south. In the Northern Shan States, south of Yunnan, the pre-Cambrian is represented by the Chaung Magyi system of phyllites and quartzites, and here it differs from that of Yunnan in containing no calcareous bands. La Touche thinks, on lithological grounds, that the Chaung Magyi series may be Cambrian, for it shows only slight signs of alteration, but a careful search of many outcrops revealed no traces of fossils, and as the rocks had been deposited, consolidated, thrown into folds and dislocated, and final-

ly subjected to denudation, before the accumulation upon them of strata containing Ordovician fossils, the stratigraphical evidence points to pre-Cambrian age.

The Bawdwin volcanic rocks, a series of tuffs and ashes interstratified with layers of true rhyolites, occurs in some localities between the Chaung Magyi rocks and the lowest of the fossiliferous series (Ordovician). At Bawdwin the tuffs and ashes have been worked for silver for hundreds of years, and very large quantities of silver-bearing lead ores have been extracted. The mineralisation of the rocks occurred as a result of a great overthrust, in the neighbourhood of which they are intensely crushed and shattered.

Ordovician.

Fossiliferous beds of this age are known in three localities, in Western Yunnan, at Pu-piao, where they consist of sandy shales or mudstones with bands of impure, hard, nodular limestone, at Shih-tien, earthy limestones and slates, and at La-mông, calcareous slates and mudstones. The fossils show a marked resemblance to those of the Northern Shan States of Burma, as is to be expected from the geographical proximity of the areas. In the Northern Shan States the lowest beds of the Ordovician (lower Naungkangyis), on the west side of the Plateau, consist largely of limestones, while to the east of the river Nam-Tu they are represented by a soft sandy marl. The next highest beds (the upper Naungkangyis) are represented, in the west, by intensely crushed shales in which all traces of the original bedding planes have been lost, and east of the Gokteik gorge, (river Nam-Tu), by bright purple clay stones. These strata, after the Plateau Limestone to be described later, are the most important formation occurring in the Shan States.

The Ordovician faunas of Eastern Yunnan and Tongking are of a different type from those of Western Yunnan and the Shan States.

Silurian.

In Western Yunnan fossiliferous slates of Silurian age occur on Shih-tien Hill and a few miles further to the south, and in East Yunnan Silurian shales pass conformably into the lower Devonian. In some parts of Tongking, the Silurian and Devonian are more or less non-fossiliferous owing to metamorphism.

In the Northern Shan States there are thin bands of graptolitic shales containing the only fossils of undoubtedly Llandovery age that have yet been found in the East. They are overlain by sandstones and conglomerates, followed conformably by sandy marls with layers of a very hard and compact limestone. The fauna is similar to that of a corresponding age in Northern and Western Europe, and absolutely distinct from the Himalayan fauna of the same period, as has been the case for all the underlying formations. With the close of the Silurian epoch, the barrier which separated

the Burmese and Himalayan life-provinces in Ordovician times was removed, changes in the distribution of land and sea brought a true middle Devonian fauna into Burma, and later a widespread transgression of the Permo-Carboniferous ocean took place over those tracts of Asia lying to the north of Gondwanaland. These changes are heralded by a series of limestones and shales, perhaps passing conformably upwards into the Plateau Limestone of Devonian age, and containing upper Silurian fossils characteristic of the Bohemian or Hercynian type, whereas, as described above, the rock formations before this contained fossils allied to Northern and Western European types.

Devonian.

The shallow-water beds of the upper Silurian period near the northern coast of Gondwanaland, now known in the Northern Shan States, and the deeper-water graptolitic shales of Yunnan further from the shore, were succeeded by a uniform thick deposit of dolomitic limestone, which forms a great area of plateau land, extending from Yunnan into the Southern Shan States, and probably continuous with the limestones in which the guano caves of Moulemein are situated. It extends an unknown distance in an easterly direction, covering a wide area in China. On the west, in the Northern Shan States, it extends to the edge of the Irrawaddy alluvium, but to the north and south of this it is separated from the alluvium by a strip of Archaean rocks. In several places its thickness can be shown to be over 5000 ft. It is remarkably homogeneous, and it is sandy to the touch and granular, although it is very pure, and not at all siliceous in reality. It has a brecciated and intensely crushed appearance, perhaps due to the great earth-movements at the close of the Mesozoic, and perhaps to sinking of the rock into solution-cavities. It is non-fossiliferous, except at one place in the Northern Shan States, called Padaukpin, not more than one hundred square yards in area, where a rich middle Devonian fauna was found, with predominating Western European types, and at one or two places in the south and north of Yunnan, where there is a close resemblance to the Padaukpin type. It is unexpected to find this type of fauna, because, as mentioned above, the life in the north of our area changed in upper Silurian times from the Western European type to that of America and Bohemia. However, the fossils cannot be regarded as necessarily typical of the Plateau limestones, on account of their extremely local occurrence.

In Yunnan and China the Devonian limestones are more bituminous and shaley than in the Shan States and Malay Peninsula. In East Yunnan pure limestones are the exception, and in Indo-China the pre-Carboniferous beds are all sandy, suggesting that the sea of that period was more shallow and less open towards the north and northeast, and the fact that the Carboniferous lime-

stone of Yunnan, Indo China, and China resembles the limestone of the Shan States suggests that, with the close of the Devonian period, the submergence advanced northwards.

Carboniferous and Permian.

In Indo-China and Cochin-China there was an unconformity between the shallow-water Devonian rocks and the succeeding Carboniferous limestones. The lower horizons of the middle Carboniferous limestones of Eastern Yunnan are sandy, and of a shallow-water type, which passes upwards into a sandy coal-bearing series with subordinate limestones, and then, in the western part of East Yunnan, into deep-water limestones. In the eastern area earth-movements took place, resulting in folds running in a northeast-southwest direction, and the denudation of these folds resulted in sandy sediments during the middle Carboniferous period, while the limestones interbedded with basic lavas were laid down during local periods of stability.

Then slow submergence took place, and enormous thicknesses (about 5000 ft.) of massive limestones now cover the area. In the eastern area there is a distinct break in the stratigraphical sequence, between the lower part of the middle Carboniferous and the upper Carboniferous limestones, owing to the folding movements just described, but the conditions during the greater part of the upper Carboniferous period were uniform deep water, resulting in an uninterrupted series of limestones, which are responsible for the unusual scenery of Eastern Yunnan at the present day. In the case of the folded series of middle Carboniferous sands and interbedded limestones the sandy beds have been denuded away easily, leaving the limestone standing out as prominent scarps, but the upper Carboniferous series of limestones, without sandy bands, has given rise to the Karst type of scenery, so called from the Karst district in Austria, dry, and almost waterless, with pot-holes and underground streams.

These Carboniferous limestones are of a very widespread nature, occurring in practically the whole of Indo-China, the Malay Peninsula, Sumatra, and in the islands of Rotti and Timor in the Archipelago, where they pass conformably up into the Permian. Permo-Carboniferous limestones are not very strongly developed in the Northern Shan States, for they have been greatly denuded there, and merely form a band lying on the Plateau Limestone. They differ from the latter in not being so intensely crushed.

In the Malay Peninsula they form very prominent groups of hills, with vertical cliffs up to 2000 ft., separated by intervening expanses of flat land with an irregular surface of pinnacles and solution-hollows, covered and smoothed over with alluvium. The type of scenery here displayed is quite different from the karstic type of Yunnan and the Shan States, although the limestone in the Peninsula too is very uniformly free from sandy bands. The difference is due to the fact that, in the Peninsula, the limestone

has been converted into coarsely crystalline marble, by pressure and heat consequent on the intrusion of the Main Range granite in Mesozoic times, and, except for occasional fissures, the limestone mass is impervious to water. Caves, characteristic also of the Permo-Carboniferous limestone (and not of the Plateau Limestone) of Yunnan and the Shan States, are common in the Peninsula, and here they frequently contain phosphate deposits derived either from bats' guano, or from a concentration of the phosphatic minerals originally contained in the limestone now dissolved to form the caves. Guano deposits are known also in the limestone caves of Moulmein in Lower Burma. The wide depressions in the plateau country of the Shan States, due to subsidence after solution of the underlying limestone, and to the crushed limestone being unable to sustain its own weight, are not met with in the Malay Peninsula, but there was one well-known case of a village sinking several feet owing to the water being pumped from an underground cave.

The series has been subjected to intense folding, although this is not evident from an examination of the numerous cliff-exposures, except in certain occasional instances, for, in nearly all cases, the structure has been completely obliterated by the deposition of surface stalactitic deposits. One exception is Gunong Ginting, near Ipoh, where several distinct overfolds are seen, only a few hundred yards apart, with the axes of folding dipping in quite different directions, and numerous readings taken in limestone pinnacles, where the cover of alluvium has been removed in mining operations, also give very different dips. These folds were accompanied by faults, as would be expected in such a massive rock, and, in addition, a series of vertical faults was formed when the Main Range granite was intruded, independent of the folding, but due to the unequal subsidence or raising of different blocks of limestone and overlying Triassic and Jurassic rocks in the molten magma. Some of these vertical faults must have been of great magnitude, for schists, almost certainly of Triassic or Jurassic age, are found faulted down against the foot of a cliff, hundreds of feet high, of Permo-Carboniferous limestone.

The above description applies particularly to the limestone of the western States of the Malay Peninsula; the calcareous series of Raub rocks east of the Main Range is similar, except that here a shaley facies is strongly developed. It is probable that the absence of shales in the west is due in part to the intense metamorphism which the series has undergone, and that certain black streaks and bands which penetrate the limestone represent their remains. There is no evidence to show that the limestone hills in the east have been formed by faulting.

The fossils of the Shan States are similar types to those of the Salt Range of India, and they resemble a few fossils from the islands of Rotti and Timor in the Malay Archipelago. The fossils of the Malay Peninsula are found only in a few localities, as, in

most places, all traces of organism have been destroyed by the recrystallisation of the limestone, and specimens of homotaxial value have been found only in Pahang, east of the Main Range, and in Patalung, Siam. The Pahang fossils yield types ranging from lower Carboniferous to Permian, whereas the Siamese fossils have been described by one author as lower Carboniferous and by another as Permo-Carboniferous. South of a line drawn east and west through Kajang in South Selangor, the limestones and shales seem to pass into an unfossiliferous shaley series, devoid of sandy beds, and non-calcareous, except for calcareous shales and shaley limestones occurring in the Muar Valley.

In Sumatra Carboniferous limestones occur, forming mountains nearly 2000 feet high, crystalline and containing black nodular chert. There are also other Palaeozoic limestones with very scanty fossils whose age has not yet been determined. Probably they too are Carboniferous to Permian.

In the Malay Peninsula and Archipelago the Carboniferous and Permo-Carboniferous limestones just described are the oldest rocks known, with the following exceptions, (i) a granite in Ambon is said to be Palaeozoic, and the granite fragments in volcanic ash near Singapore may be of the same age, (ii) a series of shales and fine-grained quartzites underlying limestone in the Langkawi Islands, perhaps corresponding with the Mergui series of shales and arenaceous rocks in Burma, underlying the Moulmein Limestone. The *Oudeschiefer* formation of the Archipelago is believed to be of Permian to Jurassic age, in spite of the fact that many geologists in the past have considered it to be Palaeozoic or even pre-Cambrian.

Folding movements, which took place towards the close of the period of formation of this very widespread series of limestones, were heralded and accompanied by a big show of volcanic activity, not, however, displayed in all parts of the area. It is evident in Western Yunnan, where the greater part of the Permo-Carboniferous series is often made up of tuff and ash beds, intercalated with thick andesitic, doleritic, and basaltic lava flows; in Eastern Yunnan, where basic lavas are found interbedded with the upper part of the middle Carboniferous limestone; in the Malay Peninsula, particularly in Pahang, east of the Main Range, where it is represented by acid, intermediate, and occasionally basic, lavas, dykes, and tuffs; near Singapore; in South Sumatra, where a series similar to that in the Malay Peninsula occurs; and in Borneo.

In Pahang, volcanic activity began probably in the Carboniferous period and continued intermittently through the greater part of the Triassic, although, as land conditions followed the deposition of the limestone, a good deal of the series has been denuded away. Evidence of the persistence of volcanic activity, during the shallow-water and land conditions, is furnished by a remarkable deposit of boulders of volcanic rocks, dyke rocks lavas and tuffs, embedded

in volcanic tuff. It is supposed to be a beach deposit formed of boulders of volcanic rocks which were exposed along the shore line, and cemented by volcanic ashes which were all the time being ejected by neighbouring volcanoes. Tuffs and lavas are interbedded with the succeeding shallow-water series of quartzites, shales, and schists, of Triassic age, both in Pahang, and, on the western flanks of the Main Range, in South Selangor.

In Central Borneo volcanic rocks of an andesitic type are interbedded with rocks which are probably of Jurassic age, and certain amphibolites there are variously held to be pre-Cambrian crystalline slates, or eruptive rocks, belonging to this Jurassic period, which have been uralitised and altered by mountain-pressure.

Permo-Carboniferous and Mesozoic volcanic rocks, including serpentine and andesite, with corresponding tuffs and breccias, and occasionally dolerites, are very widespread throughout the smaller islands of the Archipelago, though only in a few of the places, such as at Letti, where volcanic breccias are overlain by fossiliferous Permian limestone, is it possible to be sure whether they are pre-Permian or Mesozoic. In Java there are volcanic rocks known to be pre-Eocene, but nothing more definite can be stated as to their age.

Triassic and Rhaetic.

Towards the middle of the Permian period the emergence of the land from the sea began in Eastern Yunnan, and the Permo-Carboniferous limestone masses were attacked by denudation, so much so, that, in some places, they were completely removed. The shore line retreated back far to the south and west. The thick Red Beds of upper Permian and perhaps lower Triassic age, were then deposited in Yunnan, the lower part of the series in East Yunnan consisting of conglomerates, and passing up into sandstones and shales, often containing salt and gypsum. Widespread basaltic and andesitic eruptions occurred at the close of the Permian. Triassic beds are preserved in East Yunnan only where they were faulted down, and so preserved from the severe erosion to which the country was subjected at the close of the Pliocene period. The beds are alternations of marine and land deposits, passing into deep-sea deposits at the top. After the deposition of the Red beds, no more marine sediments were formed, and Yunnan has been a land surface from the upper Triassic period to the present day.

The Shan States were dry land during the greater part of the Permian and the whole of the Triassic period, and no deposition took place, except for beach deposits derived from the denudation of the Plateau limestone and the underlying rocks. In the Malay Peninsula there was probably a land-period after the formation of the Permo-Carboniferous limestone, followed by shallow-water conditions, during which the sea was dotted with lagoons, probably formed by coral-reefs, enclosing clear water suitable for the growth

of radiolaria, the silica necessary for their growth being supplied by submarine volcanic emanations. Periodical slight changes in the sea level took place, which admitted detrital matter from the neighbouring land. These conditions produced the series of radiolarian cherts, interbedded with quartzites, sandstones, and grits, which cover a large area in Kedah, South Selangor, Negri Sembilan, and Pahang, in the Malay Peninsula, and in the island of Billiton. Radiolarian rocks probably of this period are common also in Borneo, Sumatra, Celebes, Timor, Rotti, and many other islands. In the Malay Peninsula the series, in some places, is built up of deposits of chert perhaps hundreds of feet in thickness, and thicker deposits of sandy beds, while in other places the series consists of alternating bands of chert and grit or quartzite, varying from several feet to only one inch in thickness. All the beds are contorted into sharp folds, and the rocks, particularly the shales and shaley grits, have been metamorphosed by earth-movements. In Perak this series occurs only in the extreme north, where it is a continuation of the extensive development in Kedah. Further south it probably corresponds roughly with a series of shallow-water quartzites and shales, which covers the greater part of the area for thirty miles north of Taiping, and which disappears, west of the Semanggol range, under Recent alluvium. The Triassic fossil *Estheriella* was found in these shales at Semanggol.

Certain boulder clays in the Kinta Valley, which are older than the Mesozoic granite, have been provisionally allotted to the Permo-Triassic period. They are very interesting because they are the source of the greatest part of the tin deposits of the Kinta Valley. For a long time they were spoken of as alluvial deposits, until geological investigation showed that they are undoubtedly older than the granite. It is possible that they have suffered considerable alteration since the granite was intruded, and one geologist holds that they were derived from quartzites and shales which had been mineralised by the Mesozoic granite. He says that the underlying rock, known in many cases to be limestone, has been partially dissolved by underground water, and that the quartzites and shales were let down into the resulting cavity, with a consequent destruction of the bedding. The result is a clay containing a large proportion of quartz sand with varying amounts of tin-ore. That the clays are older than the granite is seen by the following facts.

- (1) Near the granite the clays are often rich in tourmaline streaks and patches, and in quartz, whereas further from the junction the tourmaline and quartz are less evident.
- (2) The clays near the granite are often richer in tin than those further away.

The tourmaline patches and quartz are derived from veins of quartz and tourmaline which traversed the clays before they became jumbled up by the solution of the underlying limestone.

The chert series of South Selangor, Negri Sembilan and Pahang is overlain by grits, quartzites, and shales, the lower portion of which includes beds of conglomerate, in which the pebbles consist in the main of quartz, quartzite, radiolarian chert, and rocks of the Pahang Volcanic series. It is probable that this quartzite and shale series is separated by a considerable unconformity from the underlying cherts and quartzites, and that strong folding movements, which affected the latter, had ceased when the shallow-water conditions of the Rhaetic and Jurassic periods had set in.

In Yunnan and parts of Indo-China there were land conditions from the upper Triassic to the present day, but the Shan sea basin, described below, extended into Yunnan, so some Rhaetic beds were formed resembling the Napeng beds of the Shan States. The Napeng beds are fossiliferous clays, sometimes calcareous, laid down on the irregular surface of the Plateau Limestone. The fossils they contain are sometimes ill-developed, owing to the fact that they lived in cups in the limestone not in free communication with the open sea, while in other places the fossils are well grown. The number of new species shows that great changes in the distribution of sea and land had taken place between the deposition of the Permo-Carboniferous and the Napeng beds, and the basin of the Shan sea was isolated from the main ocean. It extended into Yunnan, as mentioned above, and into the Malay Peninsula, where characteristic Rhaetic fossils have been found in three or four places east of the Main Range, possibly also in Singapore Island, and certainly on the west coast of Sumatra. In French Indo-China the Rhaetic period was represented by shallow-water beds also, including the coal beds of Tien Yen Lang Then.

Jurassic.

As already mentioned, there is an extensive series of shallow-water and estuarine shales and quartzites, of Jurassic age, in the Malay Peninsula. The shales have usually been converted into phyllites by the earth-movements which took place at the time of the intrusion of the Mesozoic granite masses, and they show sharp folds and faults. The shales are locally carbonaceous, and certain intrusions are known, consisting of about forty or fifty per cent carbon and the remainder siliceous material, which probably represent coal seams which were altered by the granite.

In Burma, the Mergui series of slates, argillites, clay-schists, and silicified tuffs, with subordinate quartzites and conglomerates, have been regarded as corresponding with the shallow-water Jurassic series of quartzites and shales further south in the Peninsula. However, as the Officiating Director of the Geological Survey of India in his General Report for 1920 (page 26), describes the series as underlying the Moulmein Limestone formation, it now appears that the rocks are of Carboniferous or pre-Carboniferous age, and that they correspond with the similar series

underlying the Carboniferous or Permo-Carboniferous limestone of the Langkawi Islands.

In the Dutch East Indies the pre-Cretaceous beds younger than the Permo-Carboniferous limestone are thought to be represented by the "old schist formation," already mentioned in the description of the pre-Cambrian rocks. As stated in that description, many authors have relegated it, largely on the ground of the lack of fossils, to the pre-Cambrian, and others to the Palaeozoic period, but it bears a strong resemblance to the altered shales and quartzites of the Malay Peninsula, and it was probably deposited at the same time. If this is so, the radiolarian chert beds and the Rhaetic of the Archipelago are part of the "old schist formation," or the "Malayan Series" as it was called by Volz.

In Sarawak a limestone containing middle Oolite fossils is known.

In the Northern Shan States of Burma, the Napeng beds of Rhaetic age pass conformably into the succeeding Namyau series, which consists of basal conglomerates, overlain by sandstones, shales, and clays, with very subordinate carbonaceous layers. In the greater part of the north of our area, continental conditions were prevailing (as in the Rhaetic period), and the old land surface to the northeast was gradually rising, with a consequent advance southwards of the shore line, so that the sandy sediment from it was deposited as the Namyau series. This series of beds once covered a wide area, but denudation has entirely removed it from the western portion of the Shan Plateau, and the portions still remaining only owe their preservation to the fact that they were faulted down, and so protected from the severe erosion in post-Jurassic times. The rocks are thrown into regular folds striking from N.N.E. to S.S.W.

Cretaceous.

It was probably during the Cretaceous period that the granite which runs from the Southern Shan States, through Tavoy and Mergui to the Malay States, to Singapore, and the islands of Banka and Billiton, was intruded, bringing with it tin and tungsten minerals. Dutch authors think that the granites and hornblende-granites of the Archipelago were intruded at different periods, and the granite of Amboyna is held to be older than the Permian. It may be of the same age as the granite from which the fragments in the Pahang Volcanic series ash of Singapore were derived.

Granitic rocks in Eastern Yunnan contain cassiterite, and the tin deposits of Ko-chin have been derived from them. Two French geologists agree in assigning to them a Palaeozoic age, and, if they are right, this is very interesting, as showing that the tin deposits of the area which we are considering were not all brought by granite of one period. Many of the couliesses, mentioned in the earlier part of this account, came into being as a result of the intrusion of the Mesozoic granite.

In Sumatra the granite is mostly syenitic, and whether it was intruded in Palaeozoic or Mesozoic times is not yet known. In the Malay Peninsula there are two distinct facies, a tin-bearing granite, and a hornblende-granite with associated syenite, the latter being found in the Benom Range. This hornblende-granite agrees with the hornblende-granites found in Sumatra, and elsewhere in the Archipelago, and there is no evidence of it being younger or older than the tin-bearing granite.

Sedimentary strata of Cretaceous age are known in Borneo, Java, Sumatra, and smaller islands of the Dutch East Indies, but all of the northern part of the area was a land surface subject to erosion, and no deposition was taking place there.

In Borneo certain strongly folded shallow-water sandstones and marls contain foraminifera, of which one species *Orbitolina*, makes it certain that the deposits are Cretaceous (Cenomanian). In Java there is a series of serpentinous, mica-, chloritic, and clay-schists containing limestone bands, which, in one place, contained *Orbitolina*, the fossil characteristic of the Cretaceous beds in Borneo. These limestones are nearly always granular and crystalline, without fossils. The schists are traversed by thin quartz-veins, and they are penetrated also by dykes of quartz-porphry, gabbro and dolerite.

Cretaceous rocks are found in the Arakan Yoma of Burma, and along the same line of strike, to the south, in the Andaman Islands. Marine limestones occur at the base, while the upper part of the series consists of shallow-water and estuarine deposits. Besides the granite intrusion, masses of serpentines of Cretaceous age are known, and these are penetrated by veins of the semi-precious mineral jadeite.

Tertiary.

In our area, as in Europe, there is a blank between the upper Cretaceous and the overlying Eocene deposits, which is marked by an abrupt change in the nature of the fauna, rather than by a sharply marked stratigraphical break. The igneous activity in Cretaceous times was the forerunner of earth-movements which continued during Tertiary times, affecting both the lower and upper Tertiary, although they were much stronger in the north, and in the Andaman Islands, than in the Malay Peninsula and in the East Indies.

In the Northern Shan States there is no trace of the marine Tertiary rocks which are so well developed in the plains of Lower and Upper Burma, so it is clear that, when the Tertiary sea extended over what is now the valley of the Irrawaddy, the Shan Plateau had already been raised above its waters.

Tertiary of Burma.

In Burma the Tertiary beds are represented by the following series:

Upper Tertiary	Irrawaddy system of fresh-water beds.
Middle Tertiary (lower Miocene and Oligocene)	Pegu system of marine beds.
* * *	* Unconformity * * *
Lower Tertiary (Eocene)	consisting of nummulitic limestones underlain by a shaley series containing interbedded seams of coal.
* * *	* Unconformity * * *

Cretaceous beds passing down into the Triassic.

The Tertiary coals of Burma are nearly all confined to the lower Tertiary or Eocene, being almost invariably associated with characteristic beds of nummulitic limestone. The series is about 1200 feet in thickness. Usually the coals are bright and non-laminated and they contain a large proportion of volatile matter. They are extremely friable and quickly break up under exposure. They do not cake, and they contain only a small proportion of ash.

In Tennasserim there are several localities where the coal has been reported on, and, in some cases, the seams have been shown to be of no practical value, because the seams are too small, or because of the poor quality of the coal. In Henzada district an attempt was made to exploit the coal, but the rocks are highly disturbed, (the general dip is about 60°), and transport and labour difficulties prevented operations. At Thayetmyo a mine was opened many years ago, in spite of the fact that the beds were nearly vertical, so making mining very difficult, but the two original seams gradually merged into one, and then died out, after only a little coal had been taken out, so operations were abandoned.

In Arakan district similar coal seams are found, which, on account of their highly disturbed nature, are not likely to provide large supplies, even for local use. In Shwebo district a company opened up extensive mines at Letkobin which worked for thirteen years with an annual output of 10,000 to 15,000 tons until the year 1904, when the workable coal became exhausted.

Near the Upper Chindwin River, coal seams are quite strongly developed, and, in the Nantahin-Peluswa area, of twenty five square miles, it is calculated that there are 210 million tons of workable coal. Near Pinlebu, a village twenty five miles north-west of Wuntho, there are promising coal seams of Miocene age, dipping at a low angle.

The Pegu system attains a thickness of 12,000 feet. It is important as containing the petroliferous beds which yield all the petroleum of Burma. It is marine throughout.

Pegu system	{ Kama clays Upper Prome series Lower Prome series Sitsavan shales	{ { {	Fossiliferous blue clays and sandy beds. The main oil-bearing formation of Burma.
			Fossiliferous sandstones, clays, and shales.
			Unfossiliferous shales, resting unconformably on Eocene nummulitic limestone.

The outcrop of Kama clays extends along the Irrawaddy Basin, and on it are situated the oil fields of Yenangyaung, Singu, Yenangyat, Minbu, and various smaller fields. The Petroleum, being lighter than water, has been imprisoned along the axes of the anticlines, wherever a layer of impermeable rock has formed a roof to prevent it from escaping, and bores are put down along the crests of the folds to tap it. Gases have also collected, and the mud volcanoes of the Arakan coast and at Minbu owe their origin to the escape of such gases along fissures.

The Kama clays are overlain by the Irrawaddy system of fluviatile deposits, attaining a thickness of 20,000 feet, which were once known as the "fossil-wood group" owing to the abundance of drift-wood contained in them. Emergence of the land took place in the north of our area sooner than in the south, and the retreat of the shore line from north to south began at the end of the Pegu period. In the north the Irrawaddy rocks are all fresh-water beds, whereas in the south, as in western Prome, the lower part of the Irrawaddy system includes some marine beds. Detailed work by oil geologists shows that in some districts there is considerable unconformity between the two series.

In the plain of Irrawaddy beds, east of the Irrawaddy River and in the southwest of Yunnan, strong volcanic activity took place, building up the great volcanoes of Popa and Hawshuenshan. As already mentioned, these eruptions are many miles to the west of the boundary-fault between the Tertiary rocks of the Irrawaddy Plain and the older rocks of the Shan Plateau. Popa is fifty miles northeast of the Yenangyaung oil field.

The basalt dyke at Loi Ling, in the Northern Shan States, is a Tertiary volcano, but here there was a much smaller display than in the Irrawaddy Plain and in Southwest Yunnan.

The fresh-water Tertiary beds of the Northern Shan States are silts and soft sandy rocks with seams of brown lignitic coal, filling lake basins. These basins in the older rocks are the result of faults which occurred towards the close of the Tertiary period, and the lacustrine beds in them are either of late Tertiary or Pleistocene age. They have been found in six places, the most

important being at Namma, where the area is fifteen miles long and three and a half miles wide. The coal seams are confined to the lower portion of the series. The dip averages 20° , but it varies considerably locally, perhaps due to underground solution of the limestone floor. The inferiority of the coal, and the distance of the field from the railway, make it doubtful if it is worth while to start mining operations.

Similar lacustrine deposits occur in different parts of Indo-China.

Tertiary of Malay Peninsula.

In the Malay Peninsula Tertiary beds with interbedded coal seams are known in three localities, at Rantau Panjang (in Selangor), at Enggor (in Perak), and in Perlis.

At Rantau Panjang, the coal seams are being profitably worked, the fuel finding a ready sale, for use in the tin mines and railways of the Peninsula. The thickness of the beds is not known with certainty. It appears that coal seams, interbedded with sands and shales, form the lower portion of the series, and that they are overlain by several hundred feet of shales which contain a little oil, not enough to pay for distillation. According to the usual procedure, this coal should be classed as a lignite. Its percentage of fixed carbon is less, and its percentage of moisture is higher, than that of some cheap Indian coals, and these are unfavourable properties, but its low percentage of ash, and the fact that it does not clinker, are properties in its favour.

The percentage of moisture in the Rantau Panjang coal (about 20 %) indicates an upper Miocene age. The dips in these Miocene beds range from 10° to 12° .

When this occurrence was the only Tertiary deposit that had been prospected in the Peninsula, it was thought to be a lake or swamp deposit, similar to those in the Northern Shan States, although it was then also held to be probable that its present small area, (which amounts to only a few square miles), does not represent the whole of the original area of deposition, but that much of it has been removed by denudation. However, the discovery of over 90 feet of calcareous shale, at Enggor, lying under Tertiary sands, shales, (some of which are themselves calcareous), and interbedded coal seams, suggests that the Enggor deposits, at any rate, are probably not lacustrine deposits, but marine, and that the deposits might have been comparable in extent with those of Sumatra and Burma if the Peninsula had not been subjected to severe erosion in post-Miocene times.

In Perlis the area and thickness of the coal bearing beds is unproved. A bore was made to a depth of 205 feet and was then stopped in June 1921, owing to lack of casing. Sands, clays and

sandy clays were first encountered, followed by running sands with traces of coal from 125 feet to 205 feet below the surface. The coal at Enggor and at Perlis is similar in composition to that at Rantau Panjang, and is probably of the same age.

There are still considerable areas in the Peninsula, east of the Main Range, as yet unexplored, and it is possible that in these areas there may be extensive tracts of country covered with marine and fresh-water beds, equivalent to those of the Irrawaddy plains. Such tracts provide the only possibility of mineral oil being found in payable quantities in the Malay Peninsula. Unfortunately there is no evidence that any such beds exist.

Tertiary of Sumatra.

In Sumatra there is a considerable area of Tertiary beds, both near the coast and in subsided areas inland. Near the east coast they are concealed by Pleistocene deposits. There is very little fossil evidence to go by, but the percentage of water in the interbedded brown coals gives information as to the age of the beds. The Ombilin coal field near Padang, which has been worked by the Government for many years, is of Eocene age, judging by the low percentage of moisture, and more Eocene coals occur at Gunong Tusam in North Sumatra. The younger Tertiaries in North Sumatra usually contain no coal at all, but the commonest coal occurrences in the south are in the upper Miocene beds (younger Tertiary), as at Palembang. In the Boekit Asam Field, where the estimated amount of workable coal is forty million tons, the seams are 6 to 7, 3 to 6, and 5 to 6 metres thick. This upper Miocene series with coal seams is recognised also in Djambi though the seams are diminishing in number and thickness, so it appears that the Djambi Province forms a transition from Palembang to Deli and Atjeh in the north.

No unconformity has been found in the coastal regions affecting the later Tertiaries, except that between Tertiary and very young Pleistocene strata. In the Andaman Islands, on the other hand, the Eocene is highly folded, and the Miocene, unconformable on the Eocene, is only slightly folded, showing that the main younger folding was pre-Miocene. A similar unconformity exists between the Eocene and Miocene inland in Sumatra. No information about this system of folding can be obtained from the small exposures of Tertiary (Miocene) rocks in the Malay Peninsula, except that the small dips indicate that no intense folding has occurred after Miocene times. In the Mesozoic granite there are sheared areas which are probably the result of Tertiary movements.

In the Tertiary-Quaternary period in Sumatra, there was considerable volcanic activity, generally of an andesitic type, accompanied by subordinate intrusions of quartz-porphry, porphyrite, gabbro, picrite, basalt and diorite. The upper Miocene lignite beds of Palembang have been subjected to the heat developed by the intrusion of such rocks, and their economic value has thereby been increased.

Tertiary of Java.

The greater part of Java is covered with Tertiary, Quaternary, and Recent deposits, and all the divisions of the Tertiary seem to be represented in some part, or other, of the island. The Eocene beds include compact clays, marls, and the widespread nummulitic limestones common to this period all over the world. In west Java, at Bantam, dolerites and diorites are intercalated with them and at Nanggoulan, besides basalts and olivine dolerites, lignite beds are found interbedded with the sediments.

The lower Miocene are often very much folded, and may be even vertical. Some of the beds were laid down under water, and the andesitic lava flows of this period were sometimes laid down under the sea, and sometimes on dry land.

The middle Miocene beds are less strongly developed than the lower, and they are typically marly rocks. Pyroxene-andesites are interbedded with the series in Bantam and in Preanger, but not in east or central Java. The upper Miocene beds are essentially calcareous, sometimes consisting of hard, crystalline limestone, and sometimes being soft and marly. They are markedly dolomitic. No volcanic rocks are found in this part of the Miocene series. The middle and upper Miocene beds are often folded, but usually less strongly so than the lower Miocene.

There have been reports of rich gold deposits being present in Java, but there is no foundation for them. A little gold is present in the pyrites of certain Miocene clays which have been altered by andesitic flows in the Residency of Krawang, but the commercial value of the deposit is negligible.

Eocene deposits in Bantam contain a good coal, but they are so folded, and the position of the one metre seam is made so irregular by these foldings, that it would not pay to work. There are about two million tons of fuel available here. Lignites of upper Tertiary age are known in Nanggoulan and in Bantam. Oil is obtained from Miocene beds in many localities, perhaps formed from the foraminiferal remains which they contain.

Tertiary of Borneo.

In Borneo, in the west, no Tertiary strata are found, this period being represented only by andesitic lava flows, whereas, in the southern, northern, and central parts of the island, Tertiary deposits are well developed. In Central Borneo boulders of Eocene age containing nummulites are contained in valley gravels, but these nummulitic Eocene beds are not met with *in situ*. A sandstone formation of estuarine origin, with interbedded coal seams in Central Borneo, is placed in the older Tertiary series. Generally the strata are horizontal, or only slightly tilted, but locally they are tilted and strongly disturbed and sometimes even vertical. Two seams of coal, two metres thick are being worked in Eocene beds on the island of Poeloe Laoët, off the southeast coast of Borneo. The field is estimated to contain eighty million tons of workable coal.

Recent Deposits.

They include many deposits of great economic value, such as the ruby gravels of the Mogok Valley, and the alluvial tin-deposits of Burma, the Malay Peninsula, and the islands of Banka and Billiton. Where they are devoid of minerals they usually provide very good agricultural land, and the clay beds which they contain are used for brick-making. In Borneo the old gravelly river-deposits generally contain gold, especially in west Borneo, but, although they are worked by the Chinese in certain rich spots, it has not yet been proved that they are worth working on a large scale. In the Malay Peninsula it is fairly certain that the amount of gold in similar deposits does not pay to work by European methods.

In the Malay Peninsula and in Sumatra there is evidence that the sea had a level, in recent times, higher than it has at present. In Sumatra it is indicated by raised sea-beaches, some more than 300 feet above sea-level, and also by high gravel terraces in river-basins close to the present sea shore. On the Peninsula, in Perlis, marine shells were found in a cave nearly 300 feet above sea-level, but they may have been carried there by human agency. However, biological and geological evidence combined indicate that the Peninsula was in Recent times connected to the Archipelago, so that Sumatra, Java, Borneo, and the Peninsula were united to form a continent. The sea level then rose until the Peninsula was a group of islands, and subsequent recession of the sea took place later which is believed to be still in progress at the present day. Molengraaf does not agree that Borneo has been affected by this cycle.

Under the heading of Recent deposits should be classed the deposits now being laid down by the active volcanoes in Sumatra, Java, and various islands. Barren Island, east of the Andamans, was last observed to be in eruption in 1789, and since then it has been dormant. In Borneo the Muller Mountains are built up of rhyolitic rocks, perhaps of Tertiary or of sub-Recent times, though it is also possible that they may be so old as the Cretaceous period.

It is interesting to observe that there is a close connection between the position of volcanoes, both active and recently extinct, and the lines of folding.